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Defining the Relationship Between Human Error Classes and Technology Intervention Strategies

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Introduction and Problem Statement

The *modus operandi* in addressing human error in aviation systems is predominantly that of technological interventions or "fixes." Such interventions exhibit considerable variability both in terms of sophistication and application. Some technological interventions address human error directly while others do so only indirectly. Some attempt to eliminate the occurrence of errors altogether whereas others look to reduce the negative consequences of these errors. In any case, technological interventions add to the complexity of the systems and may interact with other system components in unforeseeable ways and often create opportunities for novel human errors. Consequently, there is a need to develop standards for evaluating the potential safety benefit of each of these intervention products so that resources can be effectively invested to produce the biggest benefit to flight safety as well as to mitigate any adverse ramifications. The purpose of this project was to help define the relationship between human error and technological interventions, with the ultimate goal of developing a set of standards for evaluating or measuring the potential benefits of new human error "fixes."

It must be acknowledged and understood, however, how difficult such an endeavor is, given the wide variety of technologies and equally varied circumstances for their use, as well as the abundance of human factors data that currently exists in the literature. Therefore, we approached the problem by developing a framework for summarizing the overabundance of data in a manner that best suits two specific types of questions that users might have:

1. Given a new technology is to be implemented, which specific types or classes of human error will most likely be affected, and

2. Given that a certain type or class of human error has been identified as a major safety problem (e.g., decision errors), what kinds of technologies will most likely help in alleviating the problem?

Obviously, each question has a different emphasis and each serves a different function. Therefore, the human error data will need to be organized in a manner that allows both types of questions to be answered. In essence, the human error classes will need to be mapped onto the different classes of technology and vice versa. However, the difficulties in associated with a simple matrix are considerable for several reasons. First, there is no general consensus in the literature about the terminology used to categorize and classify errors (Senders & Moray 1991). Several different taxonomies of human error exist with varying degrees of overlap. Furthermore, there is currently no generally agreed-upon framework for classifying different technologies or intervention strategies (Wiegmann & Shappell, 1997). Thus, interconnecting human error classes with intervention technologies in a manner that is both meaningful and useful is indeed challenging (Reason, 1990).

The purpose of the present project was to explore the possibility of developing a comprehensive error-technology matrix for mapping error categories onto technology fixes and vice versa. The project had two distinct phases. The first phase, representing the first year's efforts, involved a review of the repositories of human factors data in order to examine the nature and complexity of data sources, terminologies, and classifications used to relate human error with technology intervention strategies (see Wiegmann & Rantanen, 2002 for summary of these efforts). This information was then used in Year 2 to map NASA's Aviation Safety Program (AvSP) interventions onto human error classes and to develop a prototype database that provides a structure for linking errors and technologies to help evaluate the impact that safety products will have on each error class.

Summary of Year 2 Efforts

Year 2 efforts focused on evaluating the 48 technology interventions previously generated by AvSP. Each of these is listed in Appendix A. Our evaluation consisted of several steps. The first step was to analyze each intervention based on its underlying nature or function as an intervention. This analysis involved clustering interventions into groups or categories using various taxonomies of intervention strategies. The goal of this effort was to determine the general focus or distribution of interventions. The second step involved mapping these interventions onto error categories to determine the extent to which the interventions addressed various classes of human error across different stages of accident causation (e.g., pre-crash, crash, and post-crash events). Finally, the third phased focus on the issue of evaluating the magnitude of impact that each intervention might have on the actual error category it targeted.

Intervention Categories

The AvSP technologies were initially classified by NASA into seven broad categories. These categories are accident mitigation, aviation system modeling and monitoring system, single aircraft accident prevention, synthetic vision systems, system-wide accident prevention, weather accident prevention, and aircraft icing. However, such categorization focuses more on the surface structure of the technologies rather than on their underlying theoretical or functional purpose (or at a minimum reflects a combination thereof). Therefore, we applied more traditional intervention taxonomies to better understand the nature of each intervention in an attempt to facilitate the mapping of these technologies onto error classes.

Historically, researchers and practitioners alike have proposed various ways of viewing safety interventions. In the following sections, we will briefly review each of these approaches and discuss how the AvSP technologies might be viewed using each approach. These approaches are hazard-centered, function-centered, mode-centered, and epidemiological approaches. Each is addressed in turn in the following sections.

Hazard-Centered Approach

Hazard-centered interventions focus specifically on addressing the threat to operational safety posed by a particular situation or event. As described by Wood (1979) and recommended by the International Civil Aviation Organization (ICAO, 1993), hazard-centered interventions can be classified into one of three levels:

1. Level one safety actions completely remove the offending safety hazard
2. Level two safety actions modify the system so as to reduce the risk of the underlying hazard; and
3. Level three safety actions accept that the hazard can be neither eliminated nor reduced (controlled), and therefore aims at teaching people how to cope with it.

Figure 1 shows the results of classifying the AvSP products into the three ICAO safety levels.[1] Based on the ICAO classification system, over three-quarters of the products aim at modifying the system to reduce the risks of hazards, and much smaller percentages teach people how to cope with hazards or are unclassifiable. None of the products completely removes a safety hazard. The unclassifiable products were all Aviation System Modeling and Monitoring System products that do not directly address specific hazards.

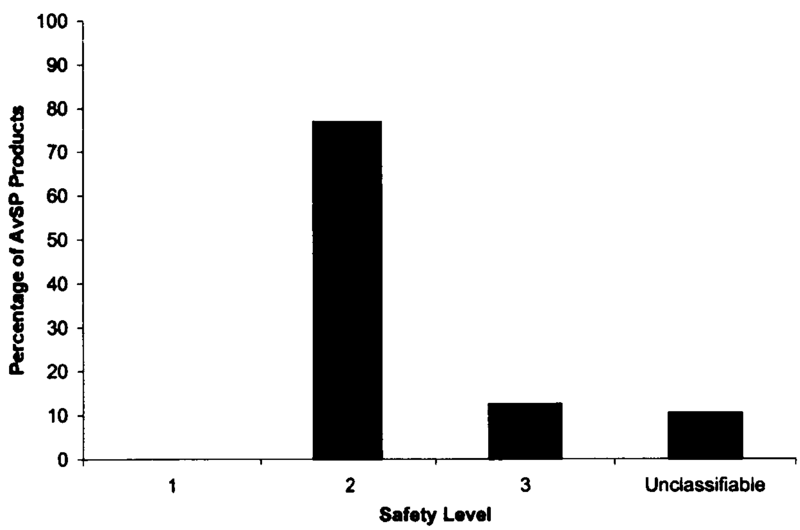


Figure 1. Percentages of the AvSP products classified into ICAO's (1993) three safety levels. Each intervention was categorized based on its single, most direct application.

Function-Centered Approach

Another way of conceptualizing technology interventions is based on whether they prevent errors from occurring or mitigate the consequences once an error occurs. The former focuses on reducing errors altogether while the latter addresses error recovery

[1] Note that Figure 1, as will all other figures presented in this section, are derived from classifying each NASA Aviation Safety Product (AvSP) into the single most applicable category for each classification system, even if the product addresses more than one category. This simplified the analysis for our initial purposes, but some categories may appear not to be as well addressed as they would be if secondary classifications were calculated on each product.

or error management. Figure 2 presents a breakdown of the AvSP interventions when examined using these two broad categories error prevention vs. mitigation.

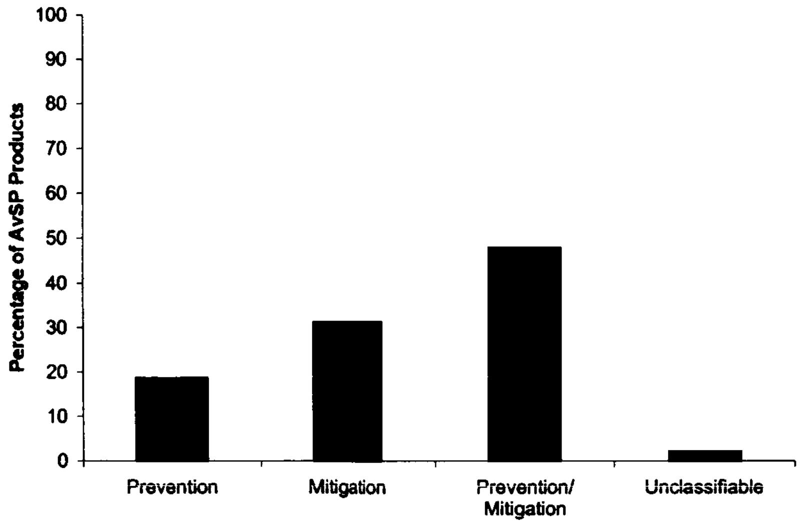


Figure 2. Percentages of the AvSP products classified as error prevention or mitigation measures.

As illustrated in Figure 2, nearly half of the products both prevent and mitigate errors, 31% solely mitigate errors, and 19% solely prevent errors. Product SAAP-6, FAA Advisory Circular and Flight Control Systems Verification Methods, accounting for the remaining 2%, could not be classified because it does not address error.

A more elaborate way of classifying intevention fuction has been proposed by Maurino, Reason, Johnston and Lee (1995). These functions include:

1. To create *awareness* and understanding of the risks and hazards.
2. To *detect* and *warn* of the presence of off-normal conditions or imminent dangers.
3. To *protect* people and the environment from injury and damage.
4. To *recover* from off-normal conditions and to restore the system to a safe state.
5. To *contain* the accidental release of harmful energy or substances.
6. To enable the potential victims to *escape* out-of-control hazards.

Figure 3 presents the distribution of AvSP technologies using this more elaborate function-centered framework. The largest proportion (44%) work primarily to protect from hazards, and 33% serve to increase awareness of hazards. The remaining 23% of the products work to detect and warn of hazards and to contain hazards. None of the products aid recovery and escape as their primary function, though some of the products assume them as secondary functions.

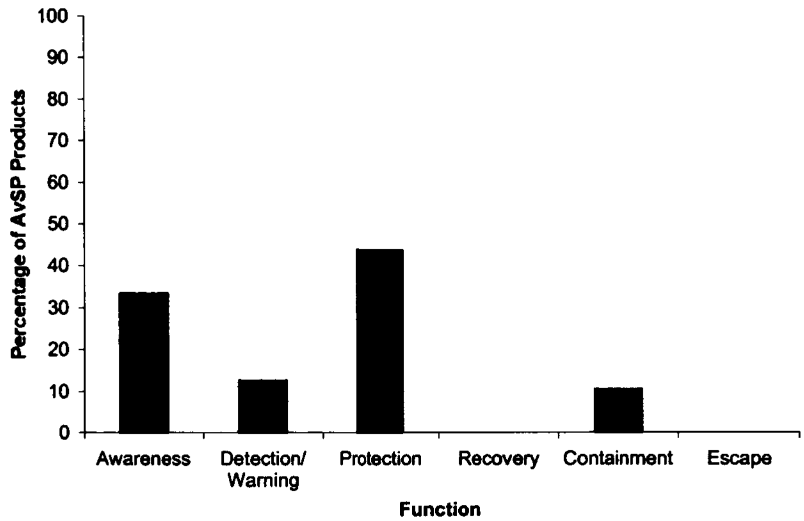


Figure 3. Percentages of the AvSP products classified into each of Reason's functions. Each product was classified into the single most applicable category.

Mode-Centered Approach

Another approach to classifying technology intervetions is based on the mode of implimentation or more specifically "what" is changed in the system to improve safety. For example, according to Wiegmann and Shappell (2003), intervetions could focus on changing the:

1. Environment (reduce heat, noise, vibration, etc),
2. Human (via selection, incentives, training)
3. Machine (design, strength, capacity)
4. Task (ordering, timing, automation)

Using this approach, the primary intervention strategies applied by AvSP products are shown in Figure 4. Most of the products increase safety by modifying the machine, or hardware components of the aviation system. Much smaller percentages of the products modify the human, environment, or task. The two unclassifiable products, Incident Reporting Enhancement Tools and Fast-time Simulation of System-wide Risks, either do not modify the system in a way that directly impacts the safety of operations or could lead to modifications of any of the categories.

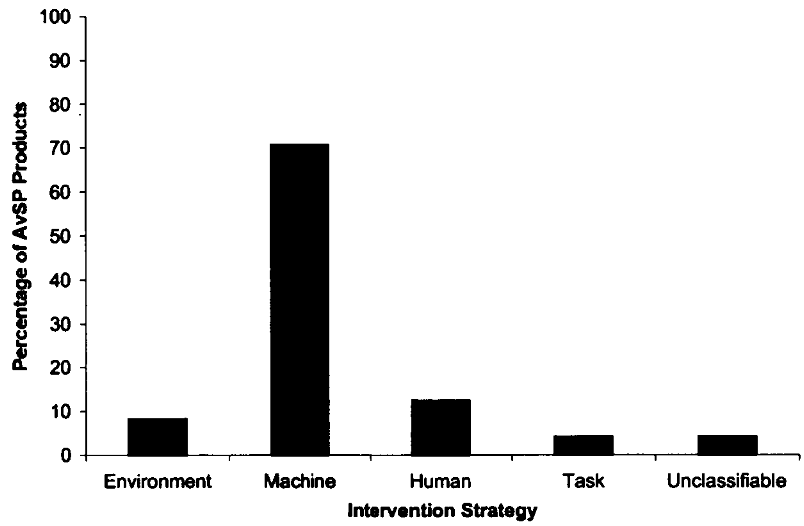


Figure 4. Percentages of the AvSP products classified by what they primarily modify to reduce accidents. Each product was classified into the single most applicable category.

Another mode centered approach has been discussed by Maurino et al. (1995). According to these authors, safety intervetions can be classified into one of five mode categories, including:

1. Engineered safety devices (flight management systems, terrain warnings, automatic detection and shutdown, etc.).
2. Policies, standards and controls (administrative and managerial measures designed to promote standardized and safe working practices.
3. Procedures, instructions and supervision (measures aimed at providing local task-related know-how).
4. Training, briefing, drills (the provision and consolidation of technical skills, safety awareness and safety knowledge).
5. Personal protective equipment (anything from safety boots to space suits).

Based on this classification system, the modes assumed by the AvSP products and their proportions are shown in Figure 5. Nearly three-quarters of the products result in interventions that primarily take the form of engineered safety features. Nineteen percent take the form of standards, policies, and controls, and the remaining ten percent take the form of training, briefings, and drills. None of the products primarily takes the form of procedures, instructions, and supervision or personal protective equipment, though some do operate secondarily as procedures, instructions, and supervision.

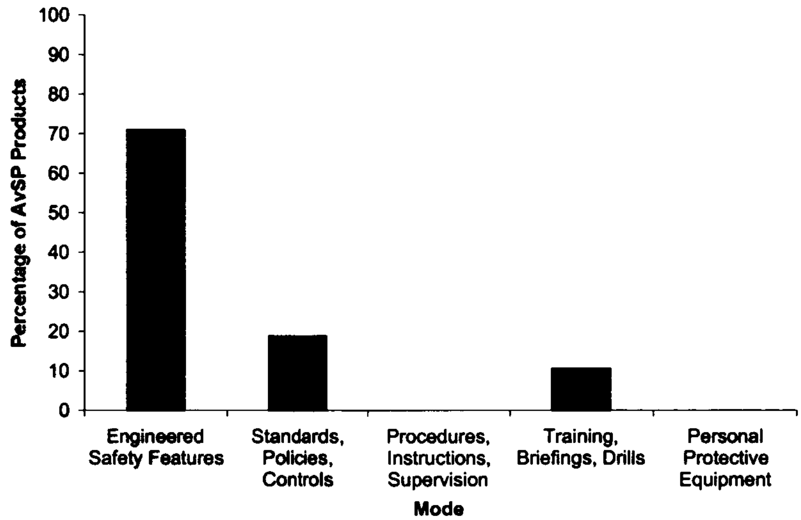


Figure 5. Percentages of the AvSP products classified into each mode category of Reason's Matrix. Each product was classified into the single most applicable category.

Epidemiolgical Approach

The epidemiological approach is based on ideas for preventing illness and injury within the occupational and public health arena, such as that presented in Figure 6. As a result, approaches to interventions can be classified as primary prevention (reduce the risk), secondary intervention (alter ways the system reacts to the risk or hazard) and tertiary prevention (minimize the damage due to hazard exposure).

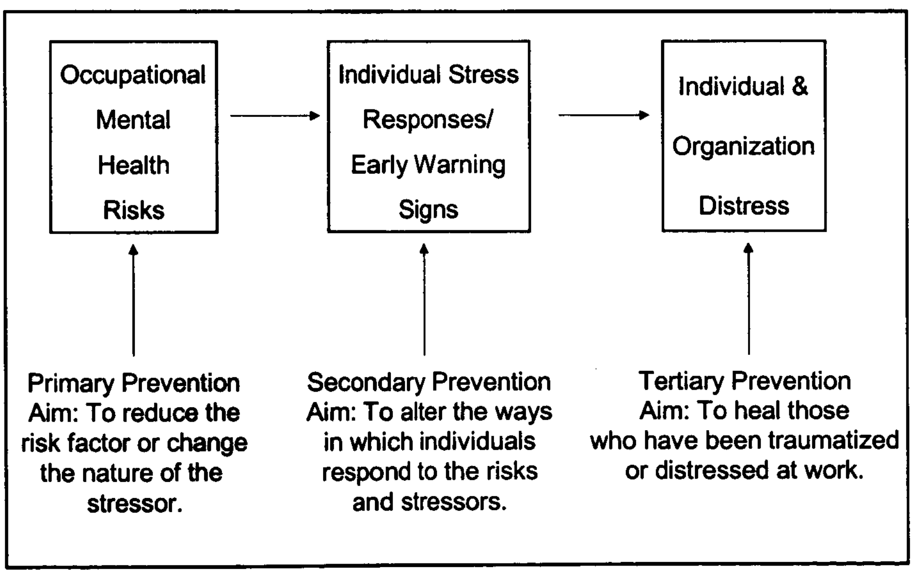


Figure 6. Model of occupational health by Quick, Murphy, Hurrell, and Orman (1993).

According to Haddon (1980) when applied to transportation accidents the three types of interventions generally map on to pre-accident (primary prevention), accident (secondary intervention) and post-accident (tertiary intervention). When AvSP interventions are considered using this framework, a distribution such as that presented in Figure 7 emerges. A large majority of the AvSP products act to maximize safety primarily before an accident or incident takes place. Seventeen percent act primarily during an accident or incident to minimize its effects, and one of the products, Elevated Flash Point Fuel Technologies, act primarily to minimize post-accident complications (e.g., crashworthiness and survivability).

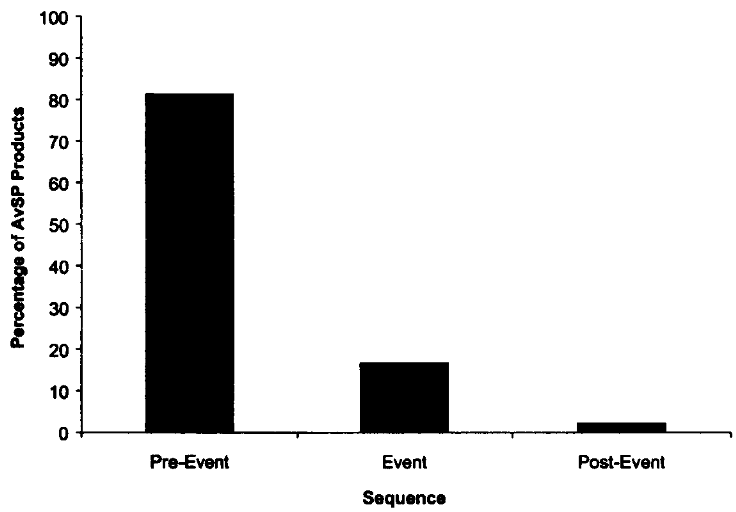


Figure 7. Percentages of the AvSP products classified by stages of an accident. Each product was classified into the single most applicable category.

Hybrid Approaches

The process of characterizing safety approaches is somewhat arbitrary and not all approaches are mutually exclusive. There can be considerable overlap across approaches. Figure 8, for example illustrates how the hazard-centered approach can be linked to the mode-centered approach (Diehl, 1989). Specifically, strategies for eliminating hazards are often environment-oriented approaches, where as safety features such as warning devices tend to be machine-oriented. Procedural approaches for dealing with hazards, in turn, are almost exclusively human-oriented.

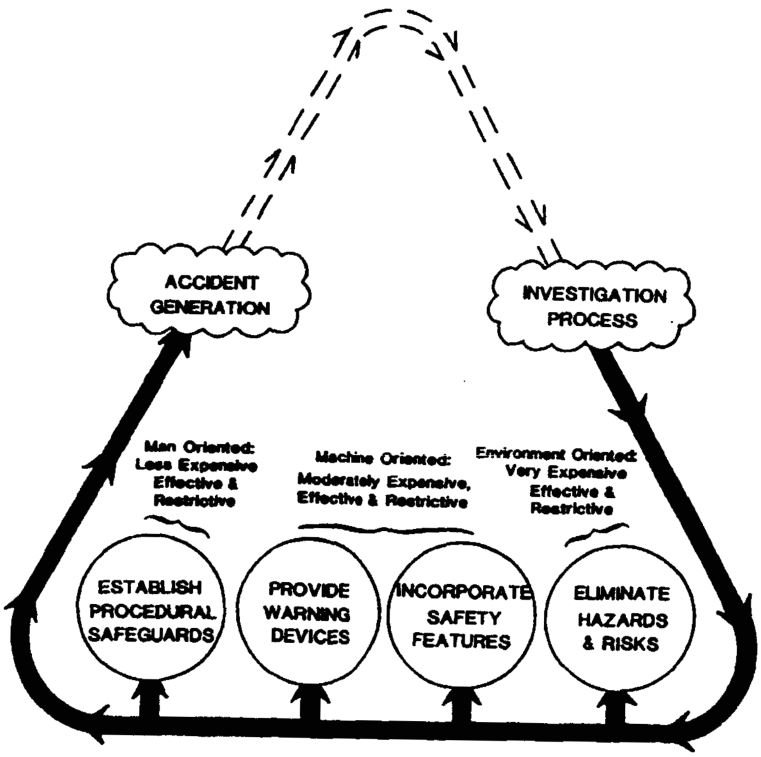


Figure 8. Accident prevention elements as described by Diehl (1989).

Maurino et al. (1995) combined the function- and mode-centered approaches to form a hybrid intervention matrix, as shown in Figure 9. When AvSP products are mapped onto this matrix, the percentages indicate that nearly 48% of the interventions are primarily engineered safety features that protect from hazards or increase awareness of hazards. An additional 23% of the products are engineered safety features that aid detection and warning of hazards or contain hazards. About 19% of the products focus on standards, policies, and controls that address awareness of or protection from hazards, and the remaining 10% primarily take the form of training, briefings, and drills in awareness of, or protection from, hazards. None of the products focus primarily on recovery or escape, and none of the products primarily take the form of procedures, instructions, and supervision or personal protective equipment. In addition, none of the products address detection and warning or containment in any mode other than engineered safety features.

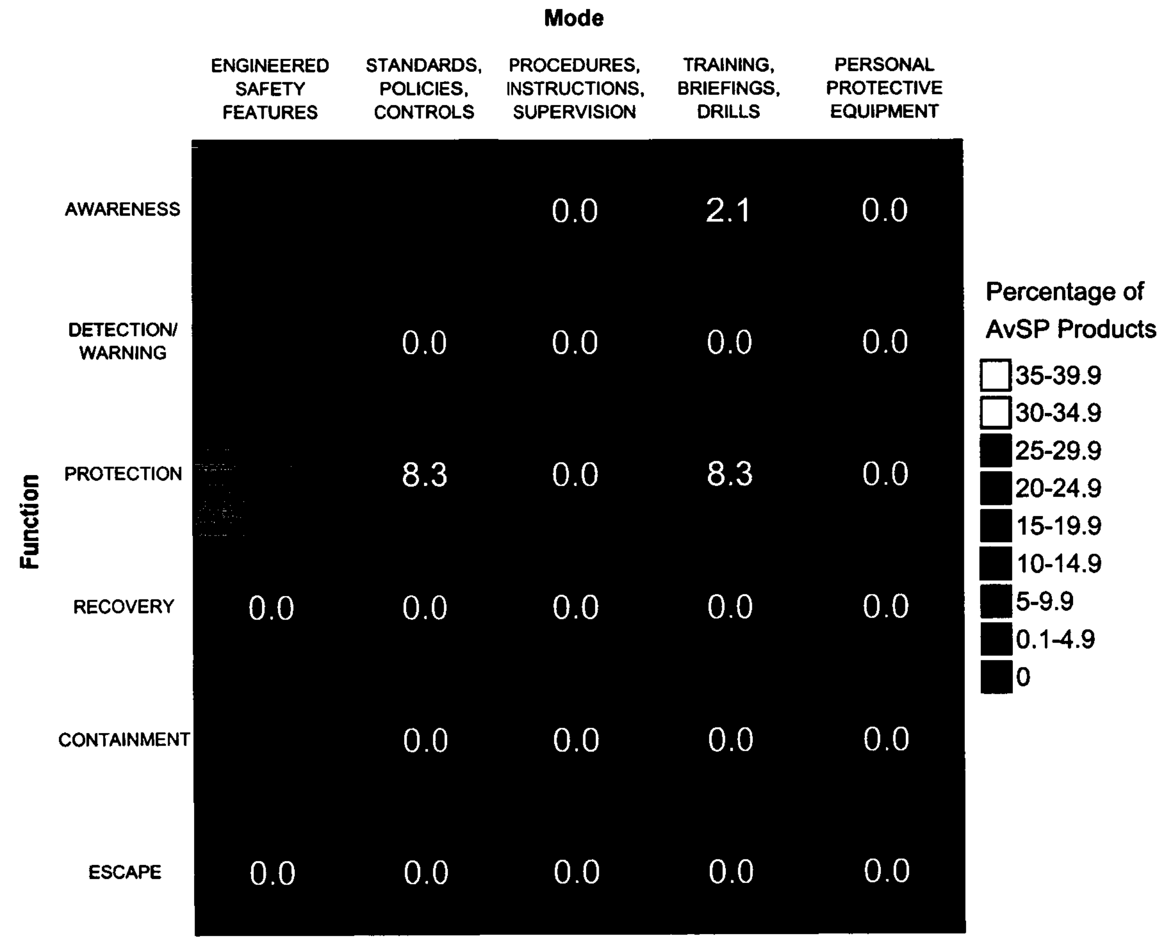


Figure 9. Maurino et al. (1995) Matrix, indicating the percentages of the AvSP products that fall into each cell. Each product was classified into the single most applicable category.

Haddon (1980) combined the mode-centered and epidemiological approaches to form the Haddon Matrix, shown in Figure 10. The percentages inside the matrix indicate the primary sequence category and system affected by each AvSP product. As illustrated in the figure, the interventions are heavily weighted toward vehicle-specific, pre-event factors, with very few focusing on post-event factors and none focusing on human- or environment-specific during- or post-event factors.

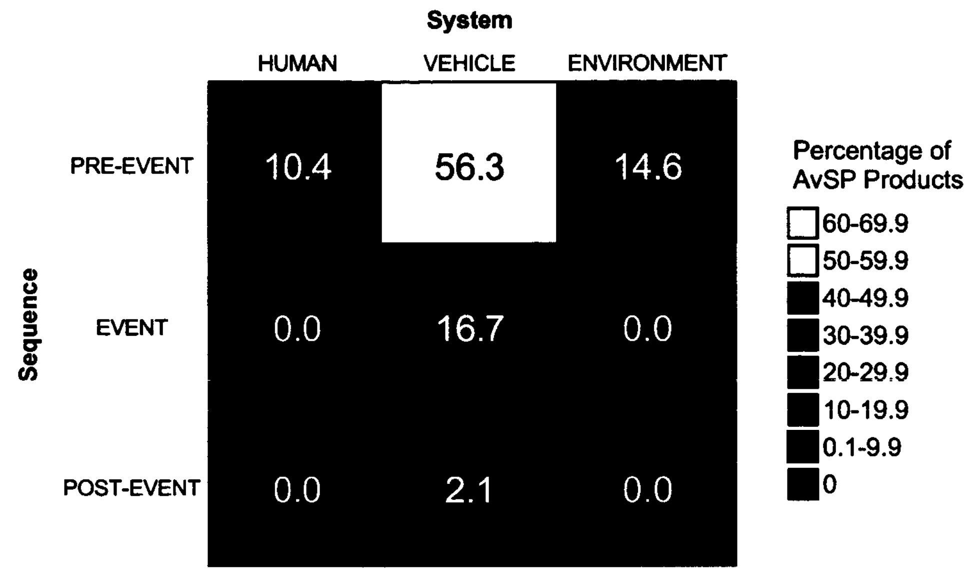


Figure 10. Haddon Matrix, indicating the percentages of the AvSP products that fall into each cell. Each product was classified into the single most applicable category.

Mapping Interventions onto Human Error Classes

In order to map intervention strategies onto human error categories, the various types of human error need to be identified and defined. In executing this phase of the project, we built upon the foundation laid down by the NASA ASAFE program, with regard to the data structures and taxonomies already in place. In particular, the Human Factors Analysis and Classification System (HFACS) has been selected as the error taxonomy, based on its use by NASA and previous reviews of the human-error literature (Wiegmann, Rich, & Shappell, 2000). A description of the error categories contained in this framework will be described in the following sections.

The Human Factors Analysis and Classification System

The Human Factors Analysis and Classification System (see Figure 11) is based upon Reason's (1990) model of latent and active failures. It addresses human error at each of four levels of failure: 1) unsafe acts of operators (e.g., aircrew), 2) preconditions for unsafe acts, 3) unsafe supervision, and 4) organizational influences. The HFACS framework was originally developed for the U.S. Navy and Marine Corps as an accident investigation and data analysis tool. Since its original development, however, HFACS has been employed by other military organizations (e.g., U.S. Army, Air Force, and Canadian Defense Force) as an adjunct to preexisting accident investigation and analysis systems. Other organizations such as the FAA and NASA have explored the use of HFACS as a complement to preexisting systems within civil aviation in an attempt to capitalize on gains realized by the military. These initial attempts, performed both at the University of Illinois and the Civil Aerospace Medical Institute (CAMI) have been highly successful and have shown that HFACS can be reliably used to analyze the underlying human factors causes of both commercial and general aviation accidents (Shappell & Wiegmann, 2001; Wiegmann & Shappell, 2001). Together, these analyses have helped identify general trends in the types of human factors issues and aircrew errors that have contributed to both military and civil aviation accidents.

HFACS: Unsafe Acts

Since the human error or unsafe acts level within the HFACS framework is central to the current research project and program goals, this level of the framework will be described briefly. The following sections will then discuss previous research findings and future research objectives in detail.

Defining unsafe acts. Within HFACS, the unsafe acts committed by pilots generally take on one of two forms, errors or violations. Errors are generally defined as mental or physical activities that fail to achieve their intended outcome. Violations, on the other hand, represent a willful disregard for rules and regulations. Some examples of aircrew casual factors associated errors and violations can be found in Table 1.

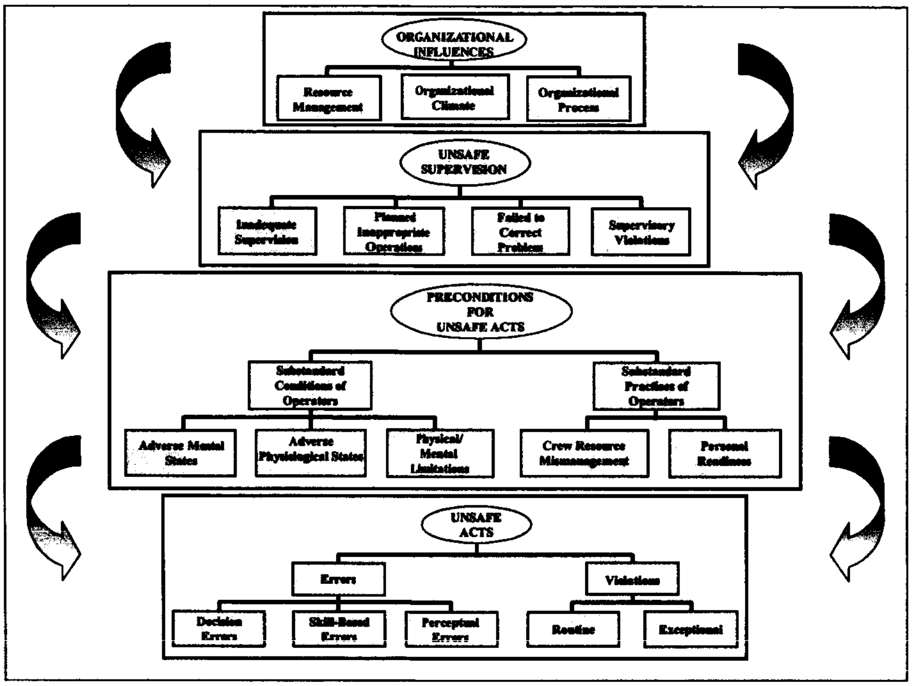


Figure 11. Categories of accident causal-factors within HFACS.

Basic error types. There are essentially three basic error types – skill-based errors, decision errors, and perceptual errors. Skill-based behavior is best described as those "stick-and-rudder" and other basic flight skills that occur without significant conscious thought. Skill-based errors may occur due to individual differences in flying skills or as a result of attention and/or memory failures. Attention failures, for example, produce such skill-based errors as a breakdown in visual scan patterns, task fixation, the inadvertent activation of controls, or the misordering of steps in a procedure. In contrast, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. Decision errors represent intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. They typically represent poor judgment, improper choice of procedure, or the misinterpretation or misuse of relevant information. Finally, perceptual errors occur when sensory input is degraded or 'unusual,' and can result in misjudged distances, altitudes, and descent rates, as well as a myriad of visual illusions.

Violations. In contrast to the three error forms described previously (decision, skill-based, and perceptual), violations represent a willful departure from those practices deemed necessary to safely conduct operations, and as such are differentiated from errors. Violations are further divided into two types based upon the characteristics of individuals committing them and those who govern their actions. Routine violations tend to be habitual by nature and are typical of the individual's behavioral repertoire. Equally important, routine violations are often perpetuated by a system of supervision and management that tolerates such departures. Exceptional violations, on the other hand, are isolated departures from authority, neither typical of the individual nor condoned by management.

Table 1
Selected examples of Unsafe Acts of Pilot Operators (Note: This is not a complete listing)

Errors

Skill-based Errors
- Breakdown in visual scan
- Failed to prioritize attention
- Inadvertent use of flight controls
- Omitted step in procedure
- Omitted checklist item
- Poor technique
- Over-controlled the aircraft

Decision Errors
- Improper procedure
- Misdiagnosed emergency
- Wrong response to emergency
- Exceeded ability
- Inappropriate maneuver

Perceptual Errors (due to)
- Misjudged distance/altitude/airspeed
- Spatial disorientation
- Visual illusion

Violations
- Failed to adhere to brief
- Failed to use the radar altimeter
- Flew an unauthorized approach
- Violated training rules
- Flew an overaggressive maneuver
- Failed to properly prepare for the flight
- Briefed unauthorized flight
- Not current/qualified for the mission
- Intentionally exceeded the limits of the aircraft
- Continued low-altitude flight in VMC
- Unauthorized low-altitude canyon running

Linking Technologies to Human Error

Figure 12 shows the percentages of the AvSP products that target each type of unsafe act. Of the products that address unsafe acts, most target decision errors, by providing better information, more highly automated systems that eliminate or reduce the need for certain decisions, or through training. Fifteen percent of the products address all errors in general, and only one of the products primarily targets skill-based errors. None of the products solely targets perceptual errors, albeit the Synthetic Vision Display products address perceptual errors but are ubiquitous, targeting decision and skill-based errors as well. None of the products primarily targets violations. Nearly half of the products did not directly target specific unsafe acts at all.

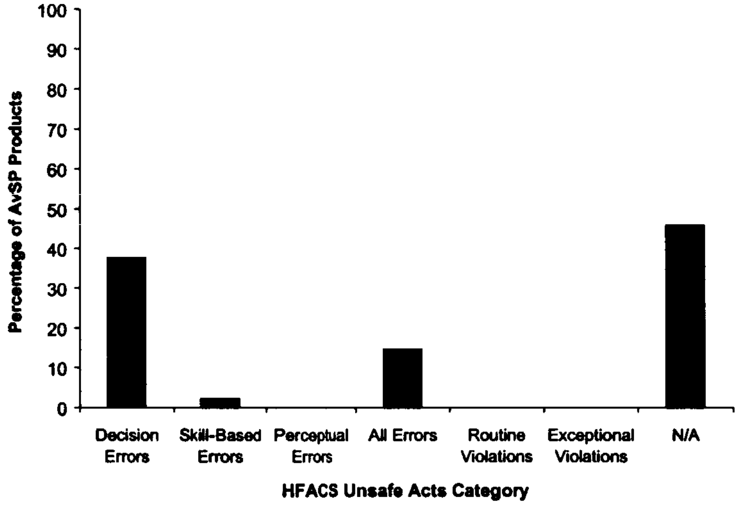


Figure 12. Percentages of the AvSP products that address the Unsafe Acts subcategories of the Human Factors Analysis and Classification System (HFACS).

Figures 13 shows the percentages of the AvSP products that target each of the unsafe acts subcategories of HFACS, broken down by each cell of the Haddon Matrix. The products that focus on human-related, pre-event factors nearly evenly target decision errors, skill-based errors, and all errors. The products that primarily address vehicle-related pre-event factors are divided between those targeting decision errors and those that do not address any unsafe acts, with a small percentage targeting all errors. Most of the products focusing on environment-related, pre-event factors do not address any unsafe acts, but one targets decision errors and one targets all errors. Half of the products primarily addressing vehicle-related, during-event factors target decision errors or all errors, and the other half do not address any unsafe acts. The single product that focuses primarily on vehicle-related, post-event factors does not address any unsafe acts.

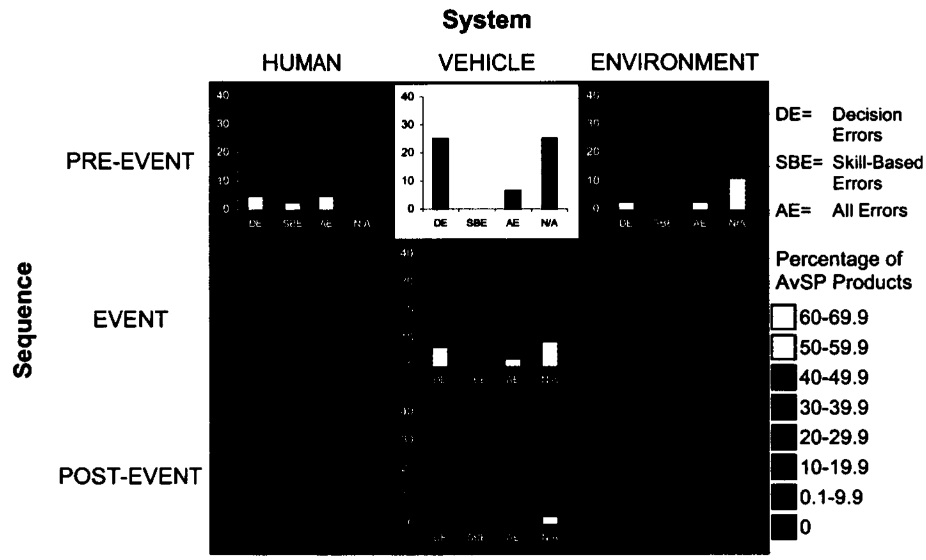


Figure 13. Haddon Matrix, with embedded graphs indicating the percentages of all of the AvSP products that target each HFACS Unsafe Acts category in each cell.

Evaluating Intervention Effectiveness

Evaluating the effectiveness of an individual safety intervention or group of intervention strategies involves two major issues. These are (1) the extent to which the interventions actually target the problems or hazards that are adversely affecting safety, and (2) the extent to which interventions will actually affect or reduce the hazard that it targets. The first issues can best be determined by examining the repository of actual accidents and incidents to determine what has caused accidents in the past. The second involves estimates of impact via a variety of methods. We will address each of these issues in turn in the following sections.

Appropriateness of Intervention Focus

In a series of studies, Shappell and Wiegmann (Shappell & Wiegmann, 2001, 2002; Wiegmann & Shappell, 2001, 2002) have analyzed the human causal factors associated with U.S. commercial and general aviation accidents using HFACS. The results are summarized in Figure 14. The top panel represents the percentage of commercial accidents (FAR Part 121 and 135 scheduled and non-scheduled air carriers) that were attributed to an unsafe act by the aircrew and the bottom panel represents general aviation (FAR Part 91) accidents. As can be seen from the figure, approximately one third of all commercial and general aviation accidents are due to decision errors by pilots and very few are due to perceptual errors. Therefore, the finding in the previous section noting that the majority of AvSP interventions target decision-making, but few address perceptual errors, is reasonable and prudent.

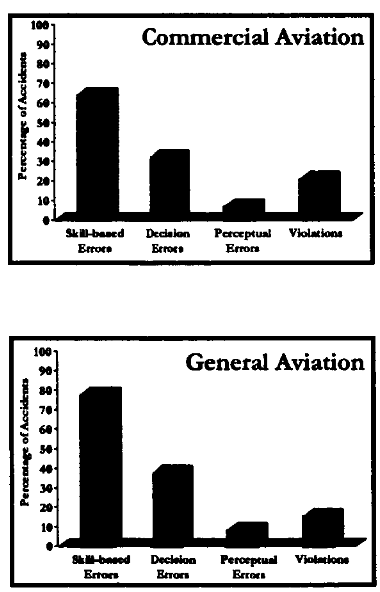


Figure 14. Percentage of commercial and general aviation accidents associated with various unsafe acts by pilots.

Also indicated in Figure 14, however, is that skill-based errors are the primary unsafe act causing accidents, and that violations of the rules also contribute to approximately one quarter of these occurrences. Yet, few AvSP interventions directly target skill-based errors and none focus primarily on reducing violations. Therefore, from this analysis, it appears that there may be gaps in the intervention being examined by AvSP and that a broader group of interventions may be needed.

Intervention Impact

To assess the potential impact that an intervention might have on reducing a hazard or particular unsafe act (i.e., human error) is more difficult than determining its applicability or relevance given the actual causes of accidents. Such estimates of impact are generally derived from expert judgments, such as those used in the generation of Bayesian belief networks (Renooij, 2001). Such judgments, however, should be based on information available from the literature describing the efficacy of the intervention under controlled conditions or effectiveness of applications of the intervention in other domains (Runyan, 1998). They could also be based on information about similar types of interventions associated with other problems or related dimensions of the intervention. To accomplish this, however, a repository or database containing relevant literature on interventions needs to exist, and more importantly, the manner for searching and retrieving such literature needs to be compatible with the goal of evaluating intervention strategies.

To accomplish this objective we have develped a prototype database and search engine for retrieving pertinent human factors literature that could be used to help determine the impact that certain technologies might have on specific types of human error. As human error is central to our approach, and human error can be understood as synonymous to human performance (i.e., poor performance or failure to perform), a human performance model is a necessary starting point for the framework mapping errors and technologies. Human performance, however, seldom happens in isolation, but is affected by a myriad of factors. These factors must necessarily be considered in the framework. Also, to successfully map human errors to various technologies and vice versa, it is obvious that a set of commonalities between each must be identified. An element common to both humans and technologies is the task. Humans use technology as tools to accomplish certain tasks, or technologies may require humans to perform tasks on them (e.g., maintenance). Hence, a system approach is deemed as the only reasonable and useful way of linking human errors with technologies. In essence, the human and the machine form a system (Rouse, 1980). According to this definition, "machine" is other than human (i.e., technology), and the human-machine interaction can be depicted in an input-output diagram, where the human's outputs are the machine's inputs and the machine's outputs are the human's inputs (Rouse, 1980; see Figure 15).

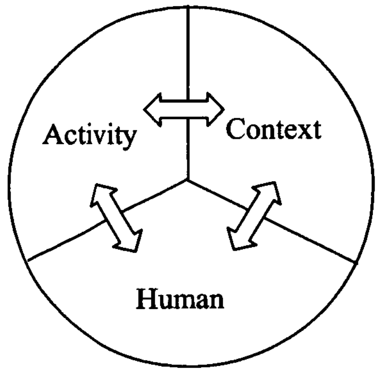


Figure 15. Bailey's (1982) qualitative model of human performance.

It is clear that the models must contain at least three critical elements: The human operator, his or her task, and the environment or context in which the task is performed. There are also several task taxonomies that entail all or parts of these elements, for example Gawron, Drury, Czaja, and Wilkins' (1989) human's taxonomy, which had three major branches: Environment, subject, and task. Although the majority of these factors remain unknown at worst and poorly understood at best, and although the number of variables and their potential interactions can be bewildering, the systems approach we have adopted offers some startling benefits in linking such disparate realms as human performance and technological innovations.

Given the multidimensional nature of the problem, the framework adopted for this proposition is five-dimensional. It consists of three axes, one for the human operator, one for the task, and one for the environment. There are several existing, published taxonomies for each axis, too. Because human errors can be mapped to all of these dimensions, albeit not uniquely, the fourth dimension of the problem can thus be placed within the "molecules" (i.e., three-dimensional cells) in the matrix. Furthermore, technologies can be mapped to tasks and environments as well as to human characteristics (e.g., *visual* displays, *auditory* alarms) and placed within the aforementioned framework. Hence, human errors and technologies will co-habit molecules in the matrix, linking them together (Figure 16).

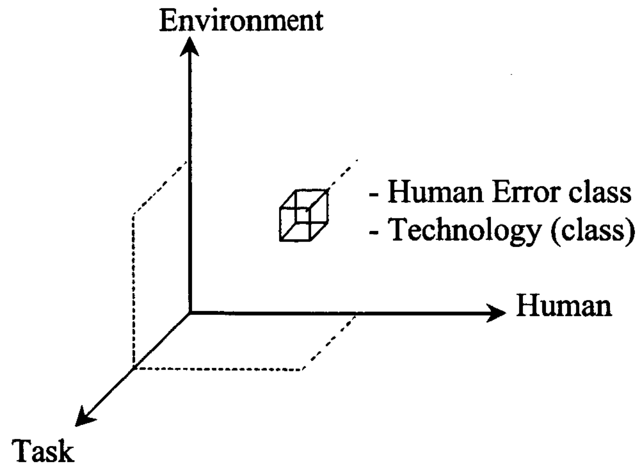


Figure 16. The five-dimensional matrix for mapping human errors and technological innovations.

Initially, we have used combinations of existing human, task, and environmental taxonomies for the three axis of the matrix. These taxonomies must remain dynamic, however, with new classes, subclasses, and sub-subclasses added or deleted according to the known technologies, their applications, and human error types that are entered into the framework. Hence, our approach serves as a vehicle for taxonomic development in all three areas pertaining to human performance and its validation will be a continuous process in lieu of a one-time effort. This framework will also direct further work deemed essential for the comprehensive solution to the problem. These efforts will be described next.

To make the proposed framework usable, it must be brought into a database format which is flexible, expandable, fully accessible by a multitude of researchers and users, and which can be continually developed as new information becomes available. Given the magnitude of the project as well as its potential value to the worldwide human factors community, a distributed development environment must be considered indispensable. We created a prototype database that accommodates all of these requirements and facilitates future development effort beyond the present project. The creation of this prototype database will be described in detail next. We will discuss the back-end (database), front-end (interface), hosting issues, and implementing the initial data set.

Selection of Database Axis Taxonomies

We selected the Human Factors Analysis and Classification System (HFACS) as the error taxonomy, based on its use by NASA and previous reviews of the human-error literature (Shappell & Wiegmann, 2001). HFACS is based on Reason's (1990) model of latent and active failures. As mentioned previously, the framework addresses the errors committed by operators as well as the preconditions and organizational factors that contributed to such errors.

The remaining axis taxonomies were chosen based on the literature review performed during Year 1 efforts. Of the task-descriptive taxonomies reviewed, we chose the Berliner, Angell, and Shearer's (1964) as the base taxonomy for the task axis. This taxonomy classified tasks according to human information processing characteristics (e.g., perception, problem-solving, and decision-making) and descriptive verbs (e.g., detects, inspects, interpolates, etc.). Hence, this taxonomy is also compatible with the taxonomy on the human axis.

The taxonomy selected for the human axis is based on the human information processing framework, which in turn is based on number of similar models proposed by different investigators (e.g., Broadbent, 1958; Smith, 1968; Sternberg, 1969; Welford, 1976). The framework chosen for our initial application is a composite of these (Wickens, 1984) and depicts human information processing in the form of sequential stages. Stimuli must be sensed in the first stage and perceived in the second. The third stage involves higher cognitive processes, such as decision-making, problem-solving, and response selection, and the fourth stage action execution. There are three other components in the model that interact with these stages: Attentional resources, and working- and long-term memory. Finally, a feedback loop closes the system.

A special subclass of the human factors taxonomies reviewed is taxonomies of environmental factors. Human performance never occurs in isolation and therefore taxonomy of human factors cannot be complete without attention to the environment. Chambers' (1969) provided a detailed and comprehensive example of the environmental variables of consideration. We expanded this taxonomy with another major subclass, that of task environment.

Finally, a technology axis was generated using the list of 48 technologies provided by NASA's AvSP. NASA initially classified the technologies into seven broad categories. These categories are accident mitigation, aviation system modeling and monitoring system, single aircraft accident prevention, synthetic vision systems, system-wide accident prevention, weather accident prevention, and aircraft icing. However, we are researching the use of the various technology taxonomies reviewed early (e.g., functional-approach) to develop methods for classifying these technology interventions to groups based on their theoretical impact.

Database

We opted to create the prototype database as a "weblication" (see Wroblewski & Rantanen, 2001), anticipating future development work that would be conducted in a widely distributed manner. Several practical questions had to be addressed and problems solved to arrive at a functional and usable database. The key decisions will be described next.

Database Software

A MySQL database was chosen as a back-end for the system for several reasons. Not only is MySQL an efficient, full-scale relational database, it is both free and open source and can be used with most platforms. Designing a workable table structure was not difficult using a relational database. However, because of the hierarchical structure of possible taxonomies it might be interesting to investigate using an object-oriented database (or a hybrid structure) to store and manipulate the taxonomic structures. This could be particularly useful when moving or changing the taxonomic structure.

Database Structure

The database structure consists of tables to hold articles, tables to hold taxonomy, including description as well as keyword, and tables that match articles to keywords. Figure 17 depicts this structure.

Interface: General Ideas

Efforts to design of an interface to an information base can generally be divided into two parts. The first might be termed "Interface Design," which describes what the user will encounter. This includes the flow of forms and printouts, the number of buttons, labels and the type of choices at each juncture. The second part concerns turning this design into reality. This includes decisions about the software for producing the forms, retrieving data from and sending information to the database and, in a web environment, how to store information about the users query during a session. This part might be called "Interface Application". Specific to the latter situation are questions about how to give the user access to the organization of the information. In this case the articles are being fitted into a taxonomic structure, which presents its own set of problems that are addressed in the next section.

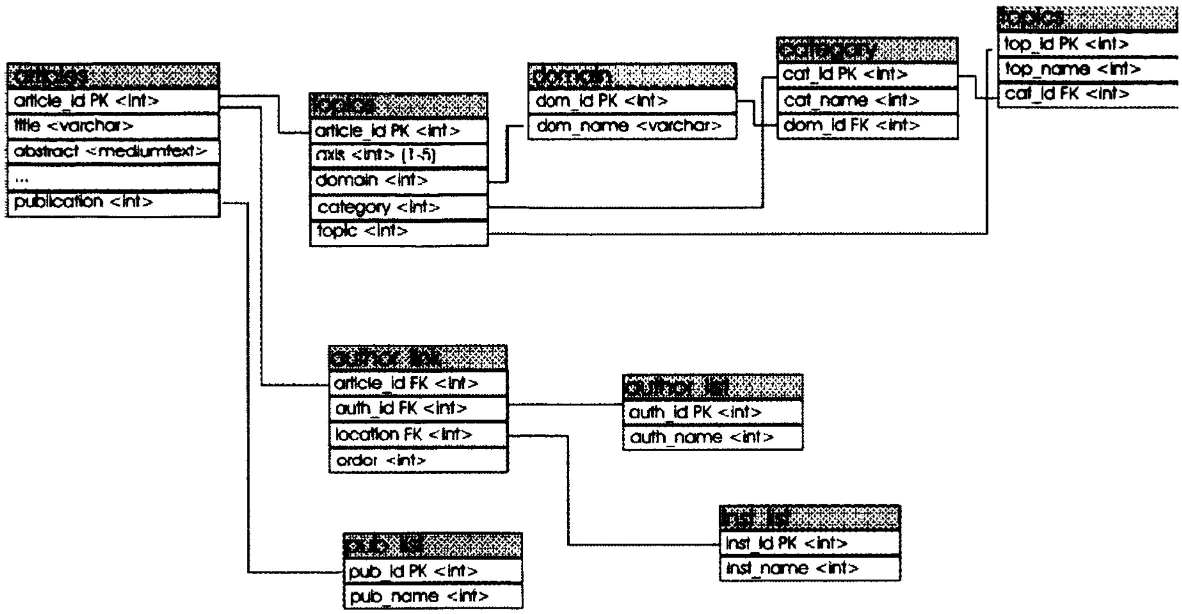


Figure 17: Database structure.

Interface Design

The project is centered around the process of indexing journal articles by fitting them into a taxonomic hierarchy. This taxonomy has been described as a 5-dimensional information space. However it might also be viewed as a tree-like structure (Figure 18). The problem of how to give the user access to the articles in this tree is both technical as well as social. The taxonomy is difficult to show all at once and the larger it gets, the more difficult it will be. Not only is this difficult to represent on a computer screen, it could overwhelm the user with too many choices. Furthermore, the user should not have to click through many screens before retrieving results. For this reason, we chose as a guiding principal to have the user start with a simple query and then give him or her the ability to make it more complex as desired. Initially the user can choose up to five search terms and retrieve results. From the results page, changes can be made to the search terms, either widening the net or tightening it, each time displaying the total number of hits and the titles. To start with, we concentrated on giving the user access to the information only through the taxonomy. Later we will add the ability to search by other metadata such as author and journal. The site layout is depicted in Figure 19.

Future Enhancements

As this is a prototype database, a number of enhancements to its usability can already be identified. We would like to provide context-sensitive help, the ability to download bibliographic entries or lists in a variety of formats (e.g., xml, bibTeX and plain text), and add thesaurus functionality to it. The latter, in addition to being an added benefit to searching the database, could be a useful recourse on its own for normalizing some of the vocabulary in the field of study.

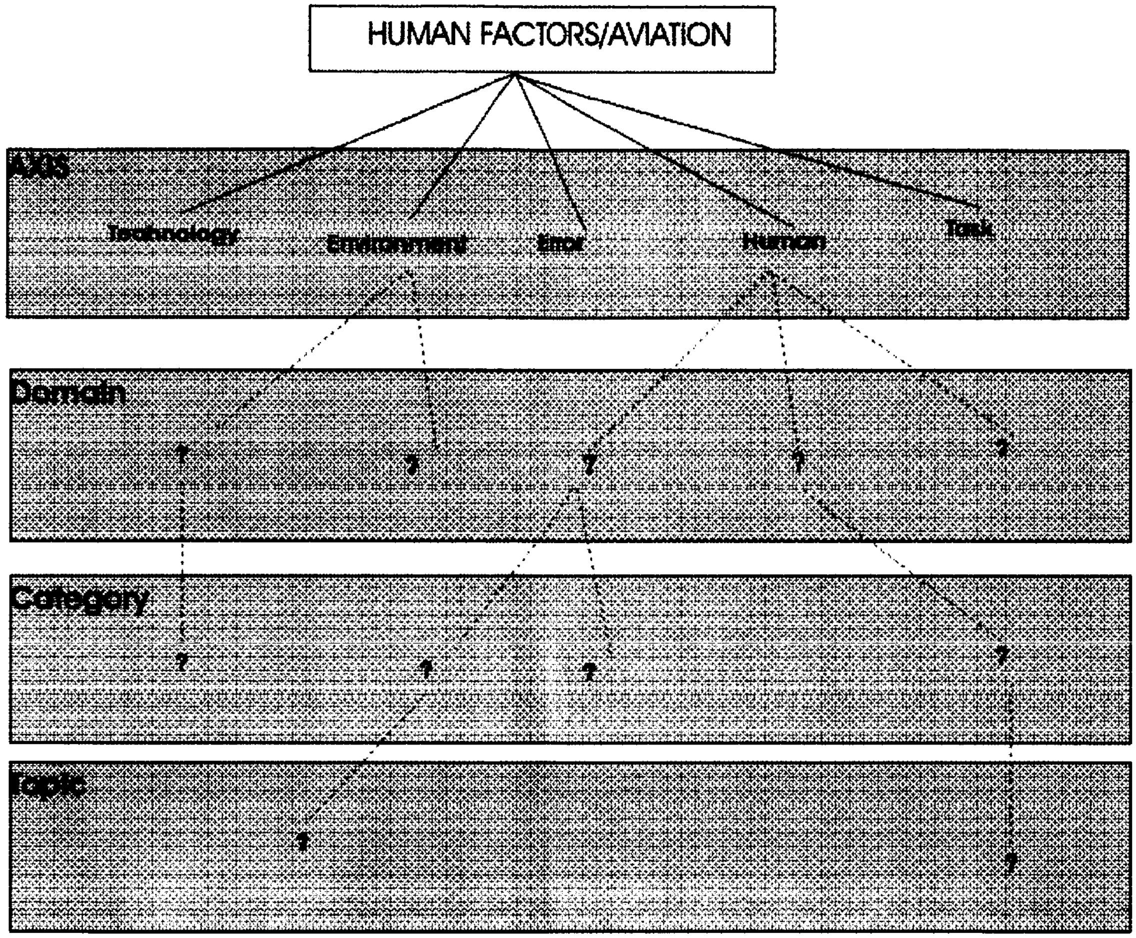


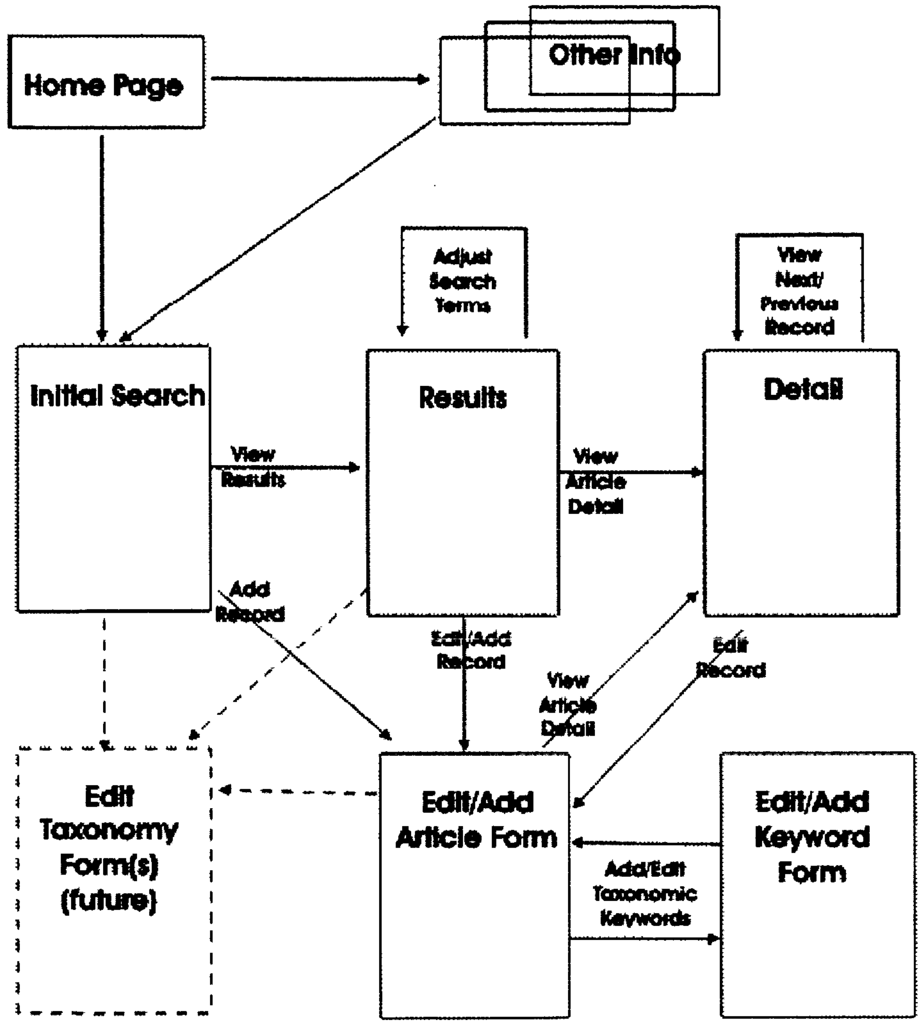
Figure 18: A tree-like depiction of the database structure

Web Access to DB

It is clear that a database of this type will ultimately serve a geographically dispersed group of users and will have to be online to be effective. For this reason, we decided that the prototype should also be made available online. By creating a web-accessible prototype, various design and technical issues such as the ones outlined in this document can be identified. Furthermore, by having the prototype database centrally accessible, we can seek assistance from others in the field during the taxonomy-building phase.

Interface Software

Perl was the programming language of choice for the web application scripts, primarily because it is freely available and ubiquitous. Perl also has well-developed libraries and drivers that allow connection to the MySQL database. However, on retrospect, perhaps an embedded scripting language such as PHP might have also been a good choice. This might have allowed both a programmer and web designers to work more closely together to create the interface.



Search/Edit Flowchart

Figure 19: A flowchart of database search.

Query Development

In a taxonomy, if a keyword has "children" that belong to it, any characteristics of that keyword would also be inherited by its "children". By design, any query for a keyword should also retrieve all items below it in the hierarchy (Figure 20). To achieve this, each keyword in the taxonomy is assigned an integer value. For the purposes of querying, it is useful to be able to express a search term or keyword along with its place in the taxonomy in one string of characters. To do this, we used a series of integers separated by a symbol. The first number represents the axis; the next represents its position in the next level and so on. In this case we used a colon to concatenate the values together. In order to retrieve the articles that match a certain keyword, a similar string of numbers and symbols is used to query matching articles. When building the query the fields are concatenated using the same symbol. Finally, in order to get all the "children" below the node a string comparison function is used along with simple pattern matching. (see: [nasa-heti.org/docs/diagrams/query.gif])

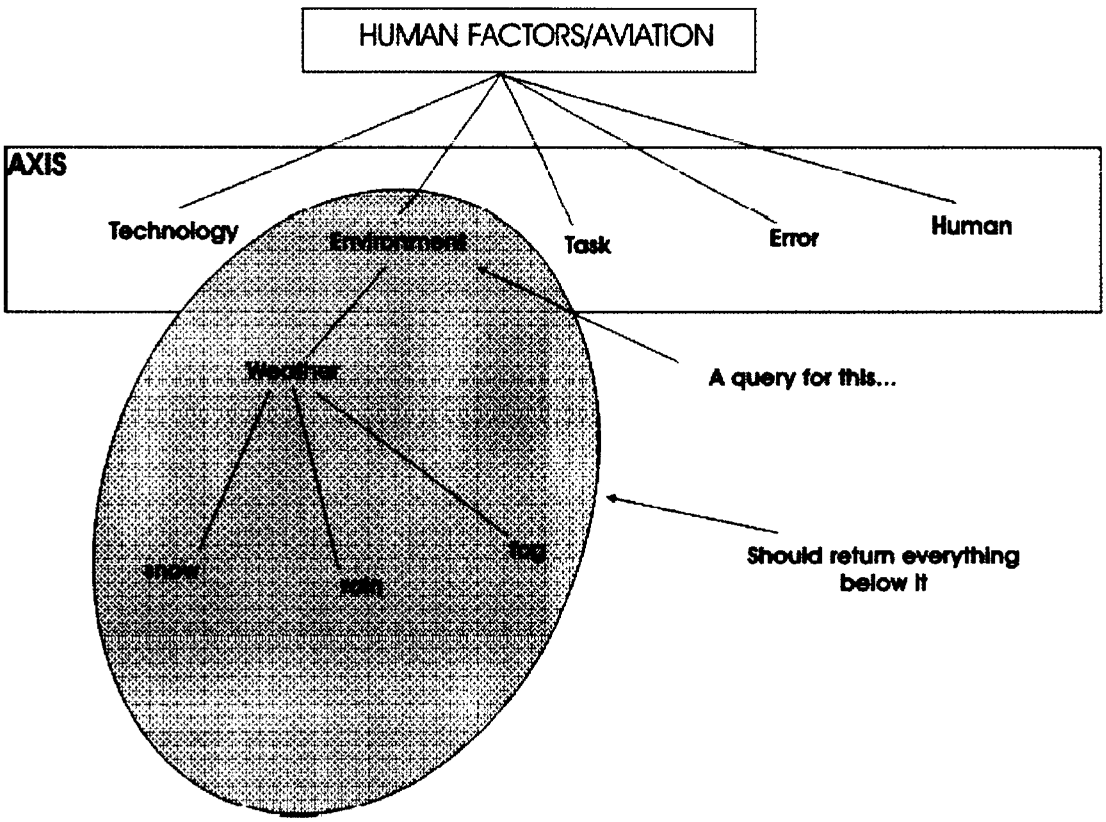


Figure 20: A keyword and its "children" in a database query.

In the relational database model, building the sort of queries we need to retrieve multiple record sets from one table is typically done using subqueries. However, MySQL does not yet support subqueries. In order to work around this issue, we used an alias for the table for each subset we need (Figure 21).

One particular query design issue remains for the future. During the taxonomy-building phase, initial query choices draw from existing keywords. In other words, users can choose from keywords that have been assigned to other articles. Presumably, after a certain amount of time, the taxonomy will be rebuilt. Keywords that are synonyms will be consolidated, groupings will be established and new terms created to "flush out" certain categories. This is important for two reasons. One of the goals of this project was to develop complete taxonomies for areas in this field. Another is to determine what research is being done or not being done within in these areas. Hence, the taxonomy should reflect all possible keywords, not just what has already been studied. Although not technically difficult, it is important that after the building phase is over the query choices should come from the taxonomy structure tables instead of existing article/keyword table.

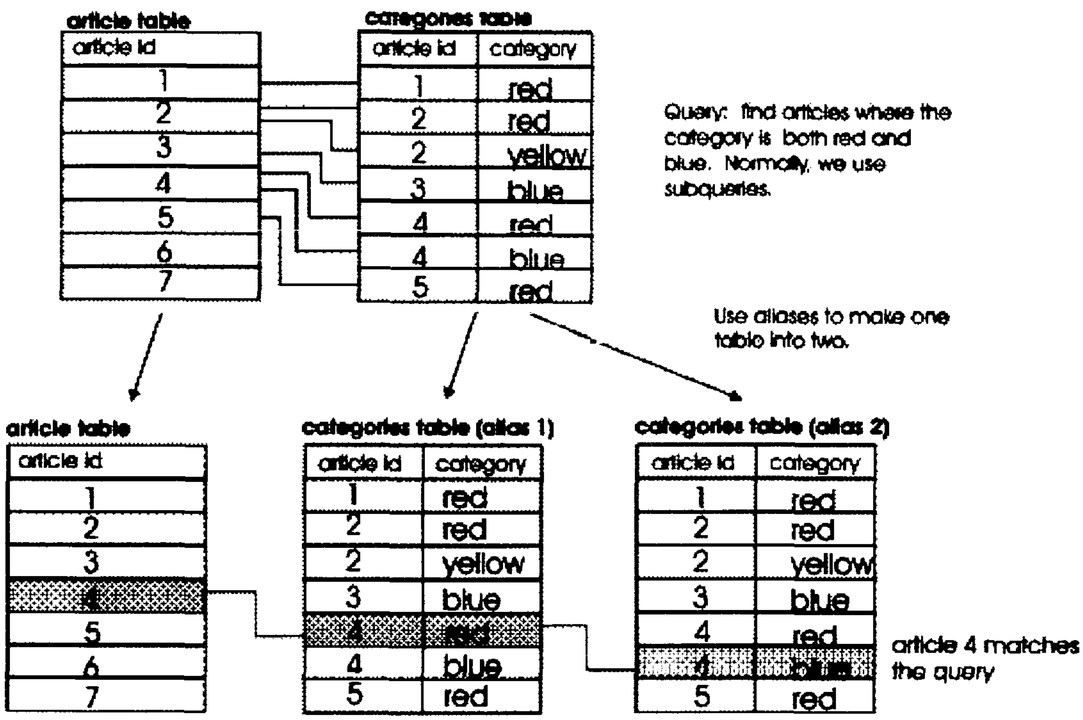


Figure 21: Subquery structure.

Website Maintenance

An additional problem in a web environment is keeping track of user information while he or she moves through the site. We have implemented server-side sessions to keep track the user's editing privileges and most recent query terms. We have also implemented a layered permission system for users with five levels of permission:

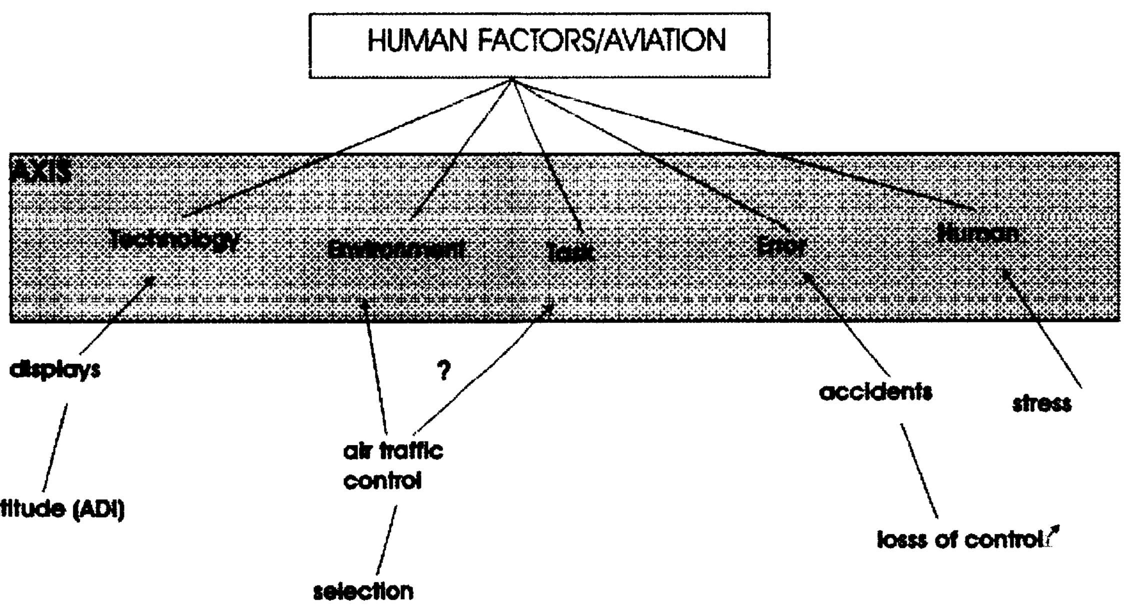
read only—search database
all of above + add articles, choose from existing keywords
all of above + add keywords entries to taxonomy
all of above + modify/delete articles entries
all of above + modify/delete keyword entries in taxonomy

Hosting Issues

A commercial Internet provider hosted the prototype database during the initial development. It was moved to www.humanfactors.uiuc.edu for a permanent home and to allow for further development and maintenance of the database

Initial Data Set

We used an initial data set consisting of metadata from approximately 400 articles from the International Journal Aviation Psychology. The articles have been indexed according to index terms given by the journal itself. These index terms may be one keyword or may also have a subheading. Instead of creating a new set of keywords, we fitted these existing keywords into the taxonomy. In some cases this was easy. In others cases, making the keywords fit into the new taxonomy was problematic. For example, "displays>>attitude (ADI)" clearly fits into the technology axis. Thus "displays" becomes the domain and "attitude (ADI)" becomes a category. However "air traffic control>>selection" could either be in environment or in task depending on the article (Figure 22).



Fitting existing IJAP index terms into the taxonomly

Figure 22: Fitting existing index terms from the International Journal of Aviation Psychology into the database taxonomy

Discussion

Proper classification of technologies is of critical importance to the outputs of our proposed framework and the prototype database, that is, accurate and comprehensive linking of technologies with human error. However, this task can be successfully completed only by conducting thorough task analysis of every technology in every application and in every environment and by all potential users. Unfortunately, there exists very few published task analyses, even for existing technologies. Although this lack of obligatory data for out framework can be seen as a drawback of the approach we adopted, it is clear that detailed scrutiny of the entries in the framework (i.e., technologies) is imperative if any useful information is to be gained. Consequently, a broad, general approach in the domain of human-machine interaction where innumerable variables and their interactions exist simply will not be justifiable. Hence, the progress that is achievable in further development of the framework and its usability are inextricably linked to the availability of task analyses associated with various technologies. On the other hand, it is conceivable that the proposed framework will become a useful and usable database that effectively reduces parallel and overlapping research efforts.

The scope of the task of providing a comprehensive mapping between technologies and human error is only beginning to emerge as the prototype database was developed. However, we strongly feel that careful attention to the creation of a robust conceptual framework is essential for success of future research, which must proceed with deliberate and systematical manner as well. Two main thrusts for further work can be identified. First, to build upon the conceptual framework presented in this paper, literature search must be extended to selected domains and all available research reviewed. Second, the framework must be "filled" with case studies, which will serve as evaluation tools as well as set an example for the complete structure.

Task analysis is an essential component of our model. Unless a thorough task analysis is conducted for each example of technology, we will not know who are the users, how the user(s) will use the technology, and how the users' performance will be affected by the technology. The method used to answer these questions is task analysis. Several techniques for task analysis exist and task analysis is an essential part of any system development.

During the database-building phase, initial query choices draw from existing keywords. Presumably, after a certain amount of time, the taxonomy will be rebuilt based on user-submitted keywords. This is important for two reasons. One of the goals of this project was to develop complete taxonomies for areas in this field. Another is to determine what research is being done or not being done within in these areas. Hence, the taxonomy should reflect all possible keywords, not just what has already been studied. Although not technically difficult, it is important that after the building phase is over the query choices should come from the taxonomy structure tables instead of existing article/keyword table.

A number of enhancements to the usability of the database can already be identified. We would like to provide context-sensitive help, the ability to download bibliographic entries or lists in a variety of formats (e.g., xml, bibTeX and plain text), and add thesaurus functionality to it. The latter, in addition to being an added benefit to searching the database, could be a useful recourse on its own for normalizing some of the vocabulary in the field of study.

In summary, the proposed database framework will allow for a directed literature search and review of both empirical and theoretical research that will help in establishing the direction of the impact of a given technology and its application on human error (i.e., a cause of an error or a remedy for an error) as well as the particular mechanisms of such relationships.

Summary and Conclusion

One of the main factors in all aviation accidents is human error. The NASA Aviation Safety Program (AvSP), therefore, has identified several human-factors safety technologies to address this issue. Some technologies directly address human error either by attempting to reduce the occurrence of errors or by mitigating the negative consequences of errors. However, new technologies and system changes may also introduce new error opportunities or even induce different types of errors. Consequently, a thorough understanding of the relationship between error classes and technology "fixes" is crucial for the evaluation of intervention strategies outlined in the AvSP, so that resources can be effectively directed to maximize the benefit to flight safety. The purpose of the present project, therefore, was to examine the repositories of human factors data to identify the possible relationship between different error class and technology intervention strategies.

The work described here reflects Year 2 efforts that focused on evaluating the 48 technology interventions previously generated by AvSP. Our evaluation consisted of several steps. The first step was to analyze each intervention based on its underlying nature or function as an intervention. This analysis involved clustering interventions into groups or categories using various taxonomies of intervention strategies. The goal of this effort was to determine the general focus or distribution of interventions. The second step involved mapping these interventions onto error categories to determine the extent to which the interventions addressed various classes of human error across different stages of accident causation (e.g., pre-crash, crash, and post-crash events). Finally, the third phased focus on the issue of evaluating the magnitude of impact that each intervention might have on the actual error category it targeted.

The results of this work suggest that AvSP technologies primarily address decision making and decision errors and that very few if any specifically target skill-based or perceptual errors or violations of the rules. The impact that these technologies will have on reducing the accident rate, therefore, may be limited given their restrictive scope. In addition, the particular impact that each intervention technology may have in reducing decision errors also needs to be examined. A prototype database for mapping interventions onto human errors to address this issue was proposed. Proper classification of technologies is of critical importance to the outputs of our proposed framework and the prototype database, (i.e., accurate and comprehensive linking of technologies with human error). Further research is needed to develop methods for using this database system to help generate judgments concerning an intervention's impact so that interventions can be effectively implemented and improvements in aviation safety can be ultimately realized.

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Appendix A

AvSP PRODUCT DICTIONARY

Based on FY03 Project Plan Data

ACCIDENT MITIGATION (AM)							
AM-1	**Next-Generation Crash Analysis Codes**	New complete suite of dynamic crash analysis software	Development of advanced analysis modules (e.g. Finite Element Modeling (FEM) elements & Subroutines) in a functionally integrated (e.g. seats and airframe together) suite of dynamic crash analysis software to make the design process more efficient, integrated, and standardized and allow certification of crashworthiness as a system rather than by individual component testing.	Aircraft manufacturers, certifiers, and operators	Lack of a functionally-integrated tool suite; time and expense of individual/empirical design and certification analyses and full-scale tests		Reduce crashworthiness design cycle time by 50%, reduce crashworthiness validation systems testing by 50%
AM-2	**Energy Absorbing Seats, Restraints and Structures**	Designs concepts and test results	Development of designs for improved energy absorbing seats, restraints, and energy absorbing aircraft structures to improve survivability in accidents.	Aircraft component manufacturers and aircraft manufacturers for small, large and transport category aircraft (initial focus on general aviation)	Improve survivability in survivable accidents by minimizing loads and maintaining habitable volumes.		Reduce impact loads by 50%
AM-4	**Next-Generation Crashworthiness Design Guidelines**	Handbook of materials test results, design and injury criteria and structural design concepts	Development of a handbook containing test results of materials tested and design guidelines for their use.	Aircraft seat manufacturers, airframe manufacturers and general aviation and air carrier operators	Reduce design/development time for new products; improve survivability in survivable accidents by minimizing loads and maintaining habitable volumes		Reduce crashworthiness validation systems by 50%
AM-5	**Fuel Tank Fire Prevention and Fire Suppression System Technologies**	Design and test results for fuel tank inerting, cargo compartment suppression and breathing oxygen generation prototype system, either combined or separately	Development of a fuel tank inerting, cargo compartment suppression and breathing oxygen generation requirements definition, prototype system and test results.	Inerting system vendors and regulators and air carrier operators	Fuel tank explosions and halon replacement		Reduce fuel tank flammability by 50%
AM-6	**Cargo Hold Fire Detection and Detection Design Guidelines**	Prototype fire detectors (i.e. gas sensors), detection system design criteria, test results, and model for cargo hold fire propagation	Development of prototype fire detectors that sense gas products of fire combustion, sensor tests and test results, sample fire tests and test results, design concept that minimize false alarms, plus a model for fire propagation; all of which can be used to eliminate high false-alarm-rate sensor.	Detection system vendors, aircraft manufacturers and air carrier operators	High false alarm rate of present sensors; operations' cost impacts		Reduce false-alarm rate by 80%
AM-7	**Elevated Flash Point Fuel Technologies**	Data on existing fuels, experimental fuels, and prototype fuel additives and test results	Technology transfer of existing experimental fuels, development and prototype fuel additives, testing for fire propagation, suppression, and flammability reduction and documentation of test results.	Fuel refiners and suppliers, air carrier operators and operators using Jet A fuels	Fire propagation in post-crash fire environment and lower flammability for fuel tank explosions		Reduce spilled fuel hazard by 50% and reduce fuel tank flammability by 50%

AVIATION SYSTEM MODELING AND MONITORING SYSTEM (ASMM)							
ASMM-1	**Incident Reporting Enhancement Tools**	Database converted to ORACLE, hardware and software to permit electronic report submission and test results for analyst decision supportsystem	Upgrade the 24-year old technology of the ASRS database to include: conversion of ASRS legacy database to ORACLE; electronic submission of reports; and test and evaluation of an analyst decision-supportsystem.	FAA; All personnel in the aviation industry including flight crews, flight attendants, mechanics, technicians, ATC, airport operations and researchers in aviation safety and human factors	Improve the collection and utilization of ad hoc safety reports from front line NAS-wide personnel.		
ASMM-2	**National Aviation System Operational Monitoring Service (NAOMS)**	Survey tool and validated methodology.	This element aims at the permanent field implementation of a National Aviation Operational Monitoring Service (NAOMS) responsible for developing and maintaining a comprehensive and coherent survey of the safety and performance of the NAS from the perspective of front line personnel NAS-wide. It is a proactive companion to the ad hoc submittal process embodied within ASRS.	FAA; All personnel in the aviation industry including flight crews, flight attendants, mechanics, technicians, ATC, airport operations and researchers in aviation safety and human factors	Creation of a mechanism for measuring the overall safety of the NAS in a quantitative, precise, and repeatable way on an ongoing basis		
ASMM-3	**Aviation Performance Measuring System (APMS) Tools**	PC-based software, documentation, training, and guidelines for APMS utilization	APMS is an integrated suite of tools to facilitate the implementation of routine flight-data analyses within each of the air-service providers. APMS develops and documents the software and procedures for data management and analyses of Flight Operational Quality Assurance (FOQA) data that enable users to easily interpret implications in safety and efficiency of flight.	Air carriers and general aviation operators -all functional disciplines, including flight operations, training, engineering and maintenance	Enable each user to implement proactive management by monitoring and analyzing large flight-recorded databases on a continuous basis.		
ASMM-4	**Performance Data Analysis & Reporting System (PDARS)Tools**	Hardware: PCs, printers, tape drives; Networking: Routers, hub, switches, DSL & T1 lines; Taps: to TRACONs and Centers; Software: tap client, server/client modules, central merge process, site adaptation; User materials: Customized sample report scripts, help information and manuals, training.	PDARS provides the capability to: collect and process Air Traffic Control (ATC) operational data (i.e., radar track and Enhanced Traffic Management System; ETMS); compute quantitative operational performance measures on a regular basis relating to system safety, delay, flexibility, predictability and user accessibility; conduct causal analyses and operational problem/issue identification and analyses; access operations' design and simulation tools for "what-if" analyses and for identification and evaluation of system improvement options; archive performance statistics and basic operational data for use in research, development, and planning studies.	FAA	Continuous, routine monitoring of performance metrics to enable the implementation of a policy of proactive NAS management.		
ASMM-5	**Fast-time Simulation of System-wide Risks**	A hierarchy of mathematical models	Rigorously validated system-wide models and simulations of relationships among elements of the NAS to support predictions and safety-risk assessments of system-wide effects of new flight and ATC technologies and/or procedures before they are inserted into the operating environment. Includes engineering models, operating concept models, support/logistics models, human performance models and risk analyses.	FAA, NASA and researchers in aviation safety and human factors	Ability to assess the safety impact of new technologies before they are implemented		

Based on FY03 Project Plan Data

ASMM-6	**Prototype System-wide Risk Assessment Capability**	PC-based software, documentation, training, and guidelines for utilization.	A capability that demonstrates the feasibility and value of automatically merging de-identified disparate data sources to assess system-wide safety risks.	FAA; all personnel in the aviation industry including, flight crews, cabin crews, mechanics, technicians, ATC, airport operations, and researchers in aviation safety and human factors.	Creation of a capability to (1) provide decision makers with reliable information on safety of the NAS; (2) identify causal factors, accident precursors, and off-nominal conditions; and (3) enable and encourage sharing of information.		

SINGLE AIRCRAFT ACCIDENT PREVENTION (SAAP)							
SAAP-1	**Condition-Based Maintenance Technologies**	Handbook of guidelines for implementaiton of condition-based maintenance	Selection of an aircraft system component (e.g., landing gear), implementation of a prototype condition-based maintenance program, followed by creation of a handbook containing operator guidelines for implementation of a condition-based maintenance program.	FAA and aviation operators	Component failures	2,6	
SAAP-2	**Real-Time Health Monitoring Technologies**	Mathematical models	System and component mathematical models to enable real-time, in-situ diagnostic and prognostic health monitoring systems. Initial target is propulsion systems - other sub systems will be selected later.	Aircraft subsystem suppliers, airframe manufacturers and air carrier operators	Component failures	2,6	
SAAP-3	**Off-Nominal Condition Detection & Alerting**	Aircraft 'state versus phase-of-flight' hazard lists and results of flight simulation tests to determine aircrew interactive cueing methodologies	Development of aircraft configuration hazards versus phase of operation data set, running flight simulation trials and developing intuitive model-based, crew alert and cueing methodologies.	Aircraft and avionics manufacturers and air carrier operators	Human errors in detection and management of malfunctions	2,3	
SAAP-4	**Outside-of-Normal-Flight Envelope Aero-model Definition**	Validated process for developing and validating large angle/rate mathematical models for control upset training; also B757-specific "outside-of-normal-flight" mathematical models.	Development of B757-specific "outside-of-normal-flight" envelope aerodynamic-math model through wind tunnel testing of a B57 model and validation of the process.	Transport category training organizations, aircraft simulator developers, aircraft manufacturers and air carrier operators	Upset prevention/recovery	1,3	
SAAP-5	**Guidance and Control Countermeasures**	Flight control software algorithms	Flight control software algorithms to implement guidance and control measures for recovery from failure/loss-of-control conditions.	Avionics and aircraft manufacturers and air carrier operators	Upset prevention and recovery	1,3,6	
SAAP-6	**FAA Advisory Circular and Flight Control Systems Verification Methods**	Advisory Circular content	Development of supporting data for an advisory circular that implements modern methods for real-time flight software verification.	FAA, flight control software suppliers and aircraft manufacturers	Increased fidelity of delivered flight software	5,8	
SAAP-7	**Integrated Flight-Critical and Non Flight-Critical Architectures**	Design guidelines for fault-tolerant integrated fligh critical system designs	This task takes a standard avionics suite with integrated flight-critical and non-flight-critical functions and induces failures in the non-critical functions to assess the impact on flight-critical functions. Design methods to prevent failure propagation are then developed.	FAA, avionics manufacturers, and air carrier operators	Futures group accident precursors	9	
SAAP-8	**Regional Engine Superalloy Disk**	Disk Component	Development of a full-scale dual microstructure heat treated Nickel-based supperalloy disk (Deliver test results and disk component indicating a disk that has higher fatigue resistant and creep growth properties better than in-service baselines.)	Engine manufacturers	Disk component failures	6,12	
SAAP-9	**Advanced Engine Containment Case**	Engine Containment System	Develop a full-scale advanced engine containment case and new computational methods and design simulation tools (Test results indicating more impact resistant and structurally lighter containment systems compared to current existing in-service baselines. Results of numerical analysis support certification considerations.)	FAA and engine manufacturers	Engine containment failures	2,3	

Based on FY03 Project Plan Data

SYNTHETIC VISION SYSTEMS (SVS)							
SVS-1	**Synthetic Vision Technology for Commercial and Business Aircra**	Demonstration avionics hardware, software, test results, design guidelines and certification strateg	Situational awareness enhancement system utilizing database, sensor, and hazard (terrain, traffic - surface and airborne, etc.) detection technologies merged with display symbology and precise GPS navigational information to create synthetic views of the aircraft's external environment for display to the flight crew.	Avionics manufacturers and operators from general aviation through transpo category aircraft	CFIT, approach and landing errors, and runway incursions		
SVS-2	**Synthetic Vision Technology for General Aviation (GA) Aircraft**	Demonstration avionics hardware, software, test results, design guidelines and certification strateg	Situational awareness enhancement system utilizing database with display symbology and precise GPS naviational information to create synthetic views of the current external environment for display to the flight crew.	Avionics manufacturers and operators of general aviation aircraft (focus on single/multi-engine piston)	CFIT, approach and landing errors and spatial disorientation upset (loss of control)		
SVS-4	**World-wide Geospatial Databses**	Example regional geospatial databases	Example regional databases and integrity monitoring technologies to provide (acquire, verify, and maintain) worldwide geospatial databases suitable for synthetic vision applications.	Avionics manufacturers, aeronautical information providers, and operators from low-end general aviation through transport category	CFIT, approach and landing errors, runway incursions and spatial disorientation upset (loss of control)		
SVS-5	**Runway Incursion Prevention Technologies**	Runway incursion detection and avoidance algorithms	Utilizes own aircraft and other aircraft or vehicle positions to alert the flight crew of potential runway incursion events.	Avionics manufacturers and operators of transport category aircraft.	Runway incursions		

Based on FY03 Project Plan Data

SYSTEM-WIDE ACCIDENT PREVENTION (SWAP)							
SWAP-1	**Human Performance Models**	Software	Human performance models that will permit the prediction of human errors due to procedural non-compliance, high workload, poor situational awareness and inadequate crew coordination issues.	In conjunction with the next product – used by aviation product manufacturers and designers during product development	Focus on reducing device susceptibility to human errors		
SWAP-2	**Crew Tracking Activity**	Software	Model of intent inferencing to determine what the crew was attempting to accomplish, what procedures are being carried out and where an error occurred, or a chain of errors began that may have led to a procedural non-compliance	In conjunction with product above – used by aviation product manufacturers and designers during product development	Focus on reducing device susceptibility to human errors		
SWAP-3	**Pilot Skill Training for Cockpit Automation**	Written guidelines and reports	Development of improved training methods for flight crews that focus on the increased use of, and integration of, automation in the cockpit.	Air carrier training departments and flight training schools	Focus on automation related human error		
SWAP-4	**Training Modules and Simulators for General Aviation**	PC-based, web-based, or video training modules	Development of training modules and simulators targeted at improving and maintaining general aviation and rotorcraft pilot skills in areas especially vulnerable to error.	Pilots and operators of light fixed-wing aircraft	Focus on general aviation crew training and currency		
SWAP-5	**Instructor Training and Evaluation**	Written guidelines and reports	Development of improved instruction in pilot training courses and methods to assess effectiveness of training.	Air carrier training departments and flight training schools	Focus on reduction of human error		

SWAP-6	**Maintenance Risk and Task Analysis Tools**	In some cases, electronic versions of the tools will be developed, otherwise written guidelines	The risk and task analysis tools are based on existing tools in the nuclear power industry. A variety of protocols and processes will be developed for maintenance human factors: (a) risk analysis of procedures to determine appropriate levels of inspection and to streamline inspection and engineering processes; (b) task/risk analysis of procedures to incorporate human factors principles of situational awareness, team coordination, communication and resource management; and (c) task analysis of procedures for improving usability and document structure.	Air carrier maintenance departments and NASA	Focus on risk reduction		
SWAP-7	**Maintenance Resource Management (MRM) Training Program for Maintenance**	Recommendations, guidelines and lessons learned	Focus is development of recommendations and guidelines to assist operators in the implementation of MRM principles into their organization. In addition to recommendations and guidelines, assessment tools are developed for the purposes of evaluating MRM skills and training. These tools cover a wide range from individual attitude surveys (applied both pre and post training), interview protocols and models for developing Return-on-Investment (ROI) metrics. New assessment techniques incorporating behavioral markers are also being developed and tested.	Air carrier maintenance, training or safety departments and contract maintenance operators	Focus on reduction of maintenance errors		
SWAP-8	**Augmented/Virtual Reality Displays**	Hardware/software and test results	a) Image-based communication and advisement system which includes the equipment and human processes involved in an image-based communication system that enables collaborative problem solving, advisement, and documentation. Imagery in CEST is comprised of scenes and views of workpieces and objects that are referents in the problem solving and advisement communications, and is recordable.	Air carrier maintenance departments, contract maintenance facilities, FAA and general aviation fleet operators	Focus on reduction of maintenance and inspection errors		
			b) Development of a virtual-reality device to train maintenance inspectors and test results. Initial prototype will be a CBT (computer-based training) interactive training tool to augment existing classroom and on-the-job inspector training. This product is based on existing virtual-reality hardware that will be upgraded and appropriate software developed.				
SWAP-9	**Human Factors Tools**	Recommendations, guidance, informative white papers, and research results	Human factors knowledge-sharing including issues and priority checklists for Project HF needs, cross-Project integration issues, display intuitiveness checklist, Program relevant bibliography	Manufacturers, developers and AvSP Projects developing human-centered products	Focus on human friendly product design		

WEATHER ACCIDENT PREVENTION (WxAP)							
WxAP-1	**Cockpit Weather System Technologies for Enhanced Situational Awareness & Decision Making**	Aviation weather information system guidelines for transports and general aviation aircraft	Results to support certification considerations, feasibility of implementation, and operational benefits of technologies including condition based maintenance	Pilots, weather service providers, avionics manufacturers	Inability of pilots to understand and effectively use cockpit weather information		
WxAP-2	**Airborne Weather Reporting Sensor Technologies**	Sensor design guidelines and test results.	Complete development of sensor design guidelines and provide associated test results. Flight demonstrate the dissemination of atmospheric data collected by the airborne Wx reporting sensor system, from a GA aircraft to a Wx product provider, in an acceptable data format	FAA or other weather service providers, NAS-wide air and ground users and non-aviation users (larger audience than aviation)	Lack of sufficient atmospheric data collection in the lower atmosphere that is needed for improved aviation forecasts and operational updates		
WxAP-3	**Weather Information Datalink Systems Technologies for Ground-to-Air Dissemination**	Datalink system design guidelines; datalink architecture guidelines	Complete development of datalink communication system design and architecture guidelines. Flight demonstrate via the dissemination of weather products to transport aircraft cockpit in national and international environment, and to GA aircraft cockpit in a national environment	Datalink service providers, avionics manufacturers and NAS-wide operators	Poor dissemination of weather information to the flight deck		
WxAP-4	**Airborne Weather Reporting Datalink Systems for Air-to-Ground and Air-to-Air Dissemination**	Datalink system design guidelines; airborne weather datalink architecture guidelines	Complete development of datalink communication system design and architecture guidelines for airborne Wx reporting. Flight demonstrate the dissemination of atmospheric data from a GA aircraft to a Wx product provider and the dissemination of turbulence in-situ data from one aircraft to another aircraft as well as to a weather product provider	Datalink service providers, avionics manufacturers and NAS-wide operators	Lack of airborne-originated data dissemination capability at lower altitude operations		

Based on FY03 Project Plan Data

WxAP-5	**Turbulence Characterization Technologies**	Validated turbulence models; in-situ algorithms	Complete development and validate turbulence models and in-situ algorithms. Flight demonstrate the dissemination of in-situ turbulence data from one support aircraft to another support aircraft resulting in display of transmitted turbulence hazard information in receiving aircraft cockpit; flight demo dissemination of in-situ turbulence data from support aircraft to a Wx product provider in an acceptable format	Pilots, FAA and other weather service providers, air carrier operators and NAS-wide air and ground users	Lack of atmospheric models for support of turbulence technology development		
WxAP-6	**Forward-looking Turbulence Sensor Technologies**	Algorithms and test results, radar/lidar prototype sensors and test results	Complete development of algorithms and provide test results; complete development of radar/lidar prototype sensors and provide test results. Flight demonstrate radar and lidar warning systems in convective and clear-air atmospheric conditions, respectively.	Pilots, Avionics and radar manufacturers, air carrier operators and turbo prop/jet operatoions	Lack of adequate or timely information in the cockpit leading to avoidance of in-flight turbulence encounters		
WxAP-7	**Turbulence Warning & Alerting Technologies**	Cockpit alerting guidelines; feasibility study results of the use of existing controls to mitigate turbulence encounters; turbulence hazard metric definitions	Complete development of cockpit alerting guidelines. Provide feasibility study results regarding use of existing controls for mitigation of turbulence encounters. Complete turbulence hazard metric definitions. Flight demonstrate turbulence hazard metrics and real-time turbulence hazard display in convective and clear-air atmospheric conditions, as appropriate.	Pilots, FAA and other weather service providers, air carrier operators and NAS-wide air and ground users	Lack of consistent turbulence alerting/warning methods, mitigation of injuries due to transport in-flight turbulence encounters		

AIRCRAFT ICING (AI)							
AI-1	**Icing Computational Tools**	Computational simulation software	Validated computational simulation software allowing for the examination of ice formation, ice protection system behavior, and the aerodynamic consequences of ice deposition.	Aircraft manufacturers, original equipment manufacturers, and regulatory authorities	Lack of validated icing simulation software	4,6,8	
AI-2	**Icing Experimental Methods**	Experimental methods, guidelines, and manuals	Experimental methods allowing for the examination of ice formation, ice protection system behavior, and the aerodynamic consequences of ice deposition.	Aircraft manufacturers, original equipment manufacturers, and regulatory authorities	Lack of sufficient understanding of experimental methods with respect to in-flight icing		
AI-3	**Icing Experimental Databases**	Experimental Databases	Publicly available experimental databases allowing for the examination of ice formation, ice protection system behavior, and the aerodynamic consequences of ice deposition. Specific topic areas include modern airfoils and droplet impingement.	Aircraft manufacturers, original equipment manufacturers, and regulatory authorities.	Lack of comprehensive, publicly available databases with respect to in-flight icing.	3	
AI-4	**Icing Avoidance Technologies**	Completion of field testing of prototype ground-based icing remote sensing system and written report.	Prototype ground-based remote-sensing system field tested in an airport environment that will: (1) improve pilot interpretation and management of icing weather hazard information transmitted to the cockpit; (2) increased all-weather dispatch and better management of air traffic in adverse weather conditions; (3) reduced in-flight icing incidents and accidents during approach and landing; and (4) increase all-weather safety and capacity	Pilots, dispatchers, forecasters, and air traffic control	Lack of real time information on icing conditions aloft.	1,2,7	
AI-5	**Icing Tolerant Aircraft Technologies**	Demonstration test through simulation (using icing flight test database) of Smart Icing Systems – Ice Management System concept design	Demonstrate through simulation (using icing flight test database) a concept design of an Ice Management System that, when fully implemented, would sense the presence of ice accretion on an aircraft, automatically activate and manage the ice protection systems, and provide the pilot with feedback including the effect on measured aircraft performance, stability and control.	Aircraft Manufacturers, Airlines, and Pilots.	Lack of automated systems in aircraft to ensure safe operation in the icing environment.	5	

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AI-6	**Icing Atmospheric Characterization Technologies**	Icing instrumentation technologies; cloud characterization databases	Understanding of the super-cooled large droplet atmospheric environment and development of instrumentation to assess the super-cooled large droplet environment.	Regulatory authorities, aircraft manufacturers, original equipment manufacturers, icing tunnel facilities, meteorologists	Lack of comprehensive understanding of natural icing conditions; Lack of validated instrumentation technologies in the super-cooled large droplet regime.		
AI-7	**Icing Education & Training Tools**	Videos, DVDs, web-based media, and computer based trainers	Provide a resource library of educational and training materials on in-flight icing that will be available to pilots and dispatchers, including the international aerospace community.	Pilots, pilot trade organizations, safety foundations, airline operators, dispatchers, regulatory authorities	Lack of education and training materials with respect to in-flight icing.	3	